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Nature conservation, Marine Protected Areas, sustainable development and the flow of invasive species to the Mediterranean Sea

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Abstract. The Mediterranean flora and fauna seem particularly rich. One of the reasons for this wealth is their high rate of endemism. In addition, the Mediterranean harbours a large variety of communities. Some of them are unique, giving the Mediterranean its touch of originality. A number of these species and communities are threatened by human activities. Until recently, the legal protection of marine species mainly concerned mammals, turtles and birds. Since 1996, 55 species of Mediterranean marine macrophytes, invertebrates and fishes were registered in Appendices I and II of the Conventions of Bern and Barcelona. Of course, the protection of species is intimately linked to the protection of their habitats and resources: a number of Marine Protected Areas (MPAs) were set up. In addition to the setting up of conservatories for threatened species and habitats, the targets of MPAs are to establish no-take areas where fish density and sex-ratio make spawning possible (which subsequently export eggs, larvae and adults to surrounding non protected areas) and to manage the different uses of the sea (e.g. artisanal fishing, recreational fishing and tourism) in a rational way, so that they do not conflict with each other or with conservation aims. Furthermore, protected areas are no longer seen as "islands" of nature surrounded by incompatible resource uses but are part of a broader regional approach to land and sea management.

More than 400 species can be considered as having been probably introduced into the Mediterranean Sea; this represents 4-5% of its known flora and fauna. Since the early 20th century, their number has more or less doubled every 20 years. As a mean, 10% of introduced species are "invasive": they play a conspicuous role in the host ecosystems, they threaten native species of communities and/or they have negative economic consequences (e.g. on aquaculture, public health and tourism). This is one of the most worrying forms of human impact, because it usually does not decrease with distance and time: it is irreversible at human scale (as coastal development and species extinction). From this point of view, introduced species undermine in an irreversible way everything that has been done to protect biodiversity, whether through the protection of species or the protection of habitats. For example, there would no longer be any point in setting up MPAs if it were merely to protect uniform meadows of introduced species, e.g. *Caulerpa taxifolia*, *C. racemosa*, *Acrothamnion preissii* and/or *Womersleyella setacea*. As far as the economic impact is concerned, it may be greater than the ecological one. This has been largely ignored in the Mediterranean countries, probably because the cost is "externalised", in such a way that those who pay are generally unaware of doing so.

By undermining the policies for the conservation of species and habitats on the one hand and economic activities on the other, invasive species change the rules of the game and turn upside down the complex equilibrium that is the cornerstone of strategies of sustainable development. Frontiers, whether administrative (MPAs) or political (countries), do not exist for invasive species. The problem can thus only be dealt with at international level. It can only be understood if the full range of aims and resource uses is taken into account: it is thus *par excellence* a problem of sustainable development.

Many international conventions (e.g. the Bonn Convention, Bern Convention, Barcelona Convention, Convention on Biological Diversity, Montego Bay Convention) recommend that countries that have ratified them should take measures to avoid the introduction of species and, if introductions should occur, to attempt to limit their spread and their impact. All Mediterranean countries have ratified at least one of these international conventions, in some cases more than 20 years ago. Nevertheless, most of them have not yet drafted a single text of law to apply the recommendations that they make. With regard to national legislation aimed at preventing and combating the introduction of species in the marine environment, most of the Mediterranean countries would thus appear to be in a total juridical vacuum (legislation levels 0 or 1), in contrast to the countries of Northern Europe and above all the United States, Canada, New Zealand and Australia (legislation levels 2, 3 and 4). Possible explanations for this inefficiency on the part of the technocratic administrative structures (i.e. the civil servants at the ministries of the environment) are discussed. Whatever the case may be, these attitudes, whether they are deliberate or stem from a certain amateurishness, incompetence or irresponsibility, raise a real problem in terms of democratic procedures: in states subject to the rule of law, can it be considered normal that international conventions, signed and ratified by elected officials, that a law voted by elected members of parliament, be flouted by non-elected civil servants?

Introduced species are one of the major environmental problems of the 21st century, at planetary scale. Through their impact on species and habitats and on resource uses and the economy, they seriously undermine strategies of sustainable development. This fact should lead decision makers and politicians to feel more concerned by this problem

INTRODUCTION

The Mediterranean flora and fauna seem particularly rich, and it does not appear to be the case that what we see is an artefact linked to the pressure of scientific investigation being greater than for other regions of the world. While the Mediterranean only represents less than 0.8% of the world ocean area, and less than 0.3% of its volume, its flora and fauna represent 7% of described species (Fredj *et al.*, 1992; Boudouresque, 1995a, 1997a; Bianchi and Morri, 2000; Boudouresque, 2004). The reasons for the general richness of Mediterranean flora and fauna are to be found in their origin. One of the reasons for this wealth is doubtless the coexistence, in the Mediterranean, of species from the boreal Atlantic, the warm Atlantic, the tropical Atlantic and the Indo-pacific. Another reason is its exceptional rate of endemism: almost 30%. Most of them are relatively recent: neo-endemics (Feldmann, 1938, 1958; Giaccone and Geraci, 1989; Bianchi, 1996; Bianchi and Morri, 2000; Boudouresque, 2004).

The Mediterranean harbours a large variety of communities, as a function of depth, substrate, mean irradiance, water movement and the annual range of temperature. Some of these communities are unique, giving the Mediterranean its touch of originality, e.g. the *Posidonia ocea* -

nica meadow, the *Lithophyllum byssoides* rim, the *Neogoniolithon bras - sica-florida* reef and the coralligenous community (Molinier, 1960; Pérès and Picard, 1964; Laubier, 1966; Sarà, 1969; Thornton *et al*., 1978; Ballesteros i Sagarra, 1984; Ros *et al*., 1985; Laborel, 1987; Bellan-Santini, 1994; Bellan-Santini *et al*., 1994; Boudouresque *et al*., 1994; Boudouresque, 2004).

The overwhelming value of biodiversity (species diversity and community diversity, the latter hereafter referred to as ecodiversity) is now largely recognized, not only by academic scientists, but also by the mass media, decision makers and public opinion (Lawton, 1994; Boucher, 1997; Costanza *et al*., 1997; Naeem and Li, 1997; Naeem *et al*., 2000; Henry *et al*., 2001).

Here, we address the issue of the conservation of this Mediterranean marine species diversity and ecodiversity, in line with the notion of sustainable development, in the context of the changes that mankind has unleashed through the spread of thousands of alien species around the planet.

THE PROTECTION OF SPECIES AND HABITATS

The realization that marine species may become extinct is relatively recent. For example, in 1809, the French naturalist Jean-Baptiste de Lamarck wrote: "*Animals living in the water, especially the sea water, are protected against the destruction of their species by man. Their multipli - cation is so rapid and their means of evading pursuit or traps are so great that there is no likelihood of his being able to destroy the entire species of any of these animals*" (translated from French). In similar vein, in 1883, Thomas Huxley said (Address to the International Fisheries Exhibition in London): "*Any tendency to overfishing will meet with its natural check in the diminution of the supply (…), this check will always come into operation long before anything like permanent exhaus - tion has occurred*". Yet several marine species had already become definitely extinct by that time. Steller's sea cow *Hydrodamalis gigas*, whose range extended from Alaska to California, became extinct in 1768, and *Pinguinus impennis*, an auk of the Northern Atlantic Ocean, disappeared in 1844.

It was mainly during the second half of the 20th century that, in order to protect species and their habitats, a number of international conventions were ratified: for example, the Washington, Bern, Bonn and Barcelona conventions. Until recently, the legal protection of marine species (banning of destruction, capture, transportation, sale, purchase, etc., living or dead) mainly concerned mammals, turtles and birds, to the exclusion of groups such as the fishes, molluscs, echinoderms, crustaceans and plants. Between the end of the 1970s and the beginning of the 1990s, about ten marine species other than mammals, turtles or birds were protected in a few Mediterranean countries (Croatia, Spain,

France and Italy). These are in particular the seagrass *Posidonia ocea - nica* and the molluscs *Lithophaga lithophaga*, *Patella ferruginea* and *Pinna nobilis*. In 1996, 55 species of Mediterranean marine macrophytes, invertebrates and fishes were registered in Appendices I and II of the Conventions of Bern and Barcelona (Boudouresque *et al.*, 1990; Ribera-Siguan, 1991; Boudouresque, 1995b, 1995c; Boudouresque *et al.,* 1996b). As far as the protection of habitats is concerned, a number of Marine Protected Areas (MPAs) were set up in the Mediterranean: e.g. Port-Cros Island (France) in 1963, Zembra Island (Tunisia; 1973), Cerbère-Banyuls (French Catalonia; 1974), Scandola (Corsica; 1975), Dor-Habonim (Israel; 1980), Ichkeul lagoon (Tunisia; 1980), Carry-le-Rouet (France; 1983), Medes Islands (Spanish Catalonia; 1983), Miramare (Trieste, Italy; 1986), Nueva Tabarca (Alicante, Spain; 1986), Ustica Island (Italy; 1986), Cabrera Island (Spain; 1991), Northern Sporades Islands (Greece; 1992) and Creus Cape (Spanish Catalonia; 1998) (Meinesz *et al.*, 1983; Cognetti, 1990; PNUE-IUCN, 1990; Ramade, 1990; Ribera-Siguan, 1991, Bachet, 1992; Ramos-Esplà and McNeill, 1994; Boudouresque, 1996; UNEP, 1997; Franceschetti *et al.*, 1999; Meinesz *et al.*, 2000; Francour *et al.*, 2001; Boudouresque, 2002a). Of course, the protection of species is intimately linked to the protection of their habitats and resources.

INTRODUCED AND INVASIVE SPECIES

An introduced species is defined as a species which fulfils the four following criteria (Carlton, 1985; Ribera and Boudouresque, 1995; Boudouresque, 1999a; Boudouresque and Verlaque, 2002). **(i)** It colonizes a new area where it was not previously present. **(ii)** The extension of its range is linked, directly or indirectly, to human activity. **(iii)** There is a geographical discontinuity between its native area and the new area (remote dispersal). This means that the occasional advance of a species at the frontiers of its native range (marginal dispersal) is not taken into consideration. Such fluctuations (advances or withdrawals) may be linked to climatic episodes. Thus, the fish *Thalassoma pavo*, which moves northwards from the southern Mediterranean during warm climatic episodes, then southwards during cold episodes, is not an introduced species in the north-western Mediterranean, where it occurs nowadays (Francour *et al.*, 1994). **(iv)** Finally, new generations of the non-native species are born *in situ* without human assistance, thus constituting self-sustaining populations: the species is established, i.e. naturalized. On the basis of this definition, the corn *Zea mais* in European terrestrial environments, and the sea mammal *Dugong dugon*, which has been observed only once along the Israeli coast and probably represents an isolated individual having entered the Mediterranean through the Suez canal (Por, 1978), are not introduced species.

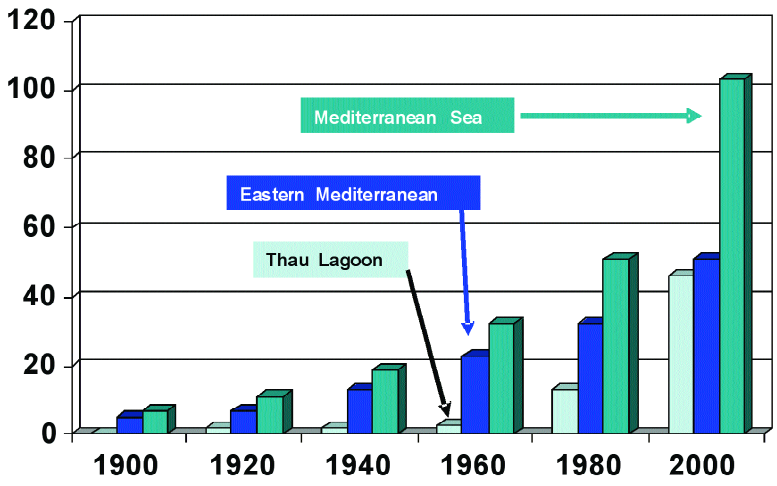

Fig. 1. Change over time in the number of introduced macrophytes in the whole Mediterranean Sea, the Eastern Mediterranean basin and the Thau Lagoon (France). From Verlaque and Boudouresque (2004).

More than 400 species can be considered as having been probably introduced into the Mediterranean Sea; this represents 4-5% of its known flora and fauna. The Mediterranean has a higher level of introduced species than any other major sea. Since the early 20th century, their number has more or less doubled every 20 years (Fig. 1). Two thirds of these species are of Lessepsian origin (i. e. entered the Mediterranean through the Suez canal), especially fishes and invertebrates (Table I). Aquaculture is the second route of introduction to the Mediterranean: the escape of aquaculture species and especially the accidental introduction of species accompanying aquaculture species. The other vectors include fouling and clinging (transportation on ships' hulls), ballast waters and escape from aquaria (Por, 1978; Zibrowius, 1991; Boudouresque and Ribera, 1994; Verlaque, 1994; Boudouresque, 1999a, 1999b; Galil, 2000; Verlaque, 2001; Boudouresque and Verlaque, 2002).

The study of a large number of species introductions, in the terrestrial environment, has led to the conclusion that, as a mean, 10% of arriving species try to settle, 10% of them actually become introduced, and 10% of introduced species are invasive. This is the "tens rule" (Williamson and Fitter, 1996). An invasive species is an introduced species the abundance of which is conspicuous, or which is playing a conspicuous role in the host ecosystems, (e.g. taking the place of a keystone species), or which threatens native species or communities, or which has negative economic consequences. Invasive species are also called

"pests". The zebra-mussel *Dreissena polymorpha* in the North American Great Lakes (Kiernan, 1993; Carlton, 1996), the comb jelly *Mnemiopsis leidyi* in the Black Sea (Konovalov, 1992; Carlton, 1996; GESAMP, 1997; Ivanov *et al.,* 2000; Kideys and Moghim, 2003) and the Chlorobionta (Plantae) *Caulerpa taxifolia* in the Mediterranean (Meinesz and Hesse, 1991; Boudouresque *et al*., 1995; Meinesz and Boudouresque, 1996; Boudouresque, 1997b, 1998) are invasive species. It is difficult, or impossible, to predict whether or not an introduced species will become invasive: it is a matter of "ecological roulette", in the phrase coined by Carlton and Geller (1993). As far as macrophytes introduced to the Mediterranean are considered, at least 9 species (the Rhodobionta *Acrothamnion preissii*, *Asparagopsis armata*, *Lophocladia lallemandii* and *Womersleyella setacea*, the Stramenopiles *Sargassum muticum* and *Stypopodium schimperi*, the Plantae *Caulerpa racemosa* var. *cylin - dracea*, *C. taxifolia* and *Halophila stipulacea*) out of the 100 introduced species can be considered as invasive, which fits well with the Williamson and Fitter's "tens rule" (Boudouresque and Verlaque, 2002).

Table I. Routes of access to the Mediterranean of probably introduced species (expressed as a percentage of the number of species). From Boudouresque (1999a), updated.

Routes of access	Flora	Fauna	Total
Fouling or clinging on ship hulls	19 %	9 %	11 %
Ballast water	2 %	2 %	2 %
Escape of species bred for aquaculture purposes	-	1 %	1 %
Accidental introduction of species accompanying oyster spat (aquaculture)	37 %	4 %	12 %
Fishing baits, escape from markets	2 %	1 %	1 %
Escape from aquariums	2 %	-	1 %
Suez Canal	31 %	73 %	63 %
Unknown	7 %	10 %	9 %

The impact of introduced species on species and communities

After habitat destruction, introduced species are the second greatest cause of species endangerment and extinction worldwide, and the first cause if only islands are taken into consideration (Simberloff, 1995; Schmitz and Simberloff, 1997).

Nothing is known about the possible impact of most of the 400 or so species introduced into the Mediterranean. Available information concerns mainly *Caulerpa taxifolia* (Plantae) in the Western Mediterranean (Meinesz and Hesse, 1991; Harmelin-Vivien *et al*., 1994; Ruitton and Boudouresque, 1994; Verlaque and Fritayre, 1994;

Boudouresque *et al.,* 1995; Cuny *et al*., 1995; Francour *et al*., 1995; Villèle and Verlaque, 1995; Bellan-Santini *et al*., 1996; Boudouresque *et al*., 1996a; Harmelin-Vivien *et al*., 1996; Lemée *et al*., 1996; Relini *et al*., 1996; Bartoli and Boudouresque, 1997; Boudouresque, 1997b; Ceccherelli and Cinelli, 1997; Chisholm *et al*., 1997; Rodríguez-Prieto, 1997; Gélin *et al*., 1998; Relini *et al*., 1998a, 1998b; Harmelin-Vivien *et al*., 1999; Rodríguez-Prieto, 1999; Harmelin-Vivien *et al*., 2001; Jaubert *et al*., 2001), *Sargassum muticum* (Stramenopiles) in the Thau lagoon, France (Gerbal *et al*., 1985; Belsher, 1991), a few Lessepsian aliens (Por, 1978; Boudouresque, 1999b), and the comb jelly *Mnemiopsis lei - dyi* (Ctenaria) in the Black Sea (Konovalov, 1992; GESAMP, 1997). Some additional data are available on the Rhodobionta *Acrothamnion preissii* in Western Italy (Piazzi *et al*., 1996), *Asparagopsis armata* in the north-western basin (Sala and Boudouresque, 1997) and *Womersleyella setacea* in Western Italy and in the Aegean Sea (Airoldi *et al*., 1995a, 1995b; Athanasiadis, 1997) and the Planta *Caulerpa racemosa* var. *cylindracea* (Argyrou *et al*., 1999; Verlaque *et al*., 2000; Buia *et al*., 2001; Ceccherelli *et al*., 2001; Piazzi *et al*., 2001a, 2001b; Dumay *et al*., 2002; Durand *et al*., 2002; Piazzi and Ceccherelli, 2002).

The conclusions which can be drawn from the available studies show that each introduced species constitutes a special case. According to species, the following has been observed (Ribera and Boudouresque, 1995; Boudouresque, 1999a, 1999b; Galil, 2000): **(i)** Zero or slight impact. It is worth noting that this statement is just a hypothesis, since species whose impact is not conspicuous have not been studied. **(ii)** More or less drastic changes in the number and/or abundance of native species. **(iii)** Displacement of a native species occupying a close ecological niche. For example in the Thau lagoon (France), the introduced Stramenopile *Sargassum muticum* has replaced another Stramenopile, *Cystoseira barbata* (Gerbal *et al*., 1985). Along the Levantine coasts, the introduced asteroid *Asterina wega* appears to have locally replaced the native, ecologically similar *Asterina gibbosa* (Por, 1978). The native prawn *Penaeus kerathurus*, which supported a commercial fishery throughout the 1950s, has now nearly disappeared; it is replaced by *P. japonicus* (Spanier and Galil, 1991). **(iv)** Changes in the functioning of native ecosystems, due to an introduced species which acts as a key-species. **(v)** Displacement of native ecosystems, due to the setting up of a totally new ecosystem. This is the case of the *Caulerpa taxifolia* meadow, which can take the place of most of the indigenous communities of the sublittoral zone, e.g. *Cystoseira* photophilic communities, sciaphilic communities and the seagrass *Cymodocea nodosa* meadow (Verlaque and Fritayre, 1994; Boudouresque *et al*., 1995; Boudouresque, 1997b; Relini *et al*., 1998a; Harmelin-Vivien *et al*., 1999; Rodríguez-Prieto, 1999).

Nature conservation and sustainable development

Until the late 1960s, the key concept behind protected areas was that they were areas not materially altered by human exploitation or occupation, and that steps should be taken by the competent authority to prevent or eliminate exploitation or occupation. So protected areas were seen as "islands" of nature and tranquility surrounded by incompatible resource uses (McNeely, 1994a; Raffin, 2001). Yet such an "island" mentality is fatal in the long term because protected areas will not be able to conserve biodiversity if they are surrounded by degraded habitats that limit gene-flow, alter nutrient cycles, provide invasive species and cause regional climate change which may ultimately lead to the disappearance of these "island parks" (McNeely, 1994a; Boudouresque *et al.,* 2004). Invasive species clearly illustrate this problem. The park boundary of the Port-Cros National Park (France) offered no protection from the immigration of *Caulerpa taxifolia* and *C. racemosa* var. *cylindracea*, once they were present along the coasts of the French Riviera (Cottalorda *et al*., 1996; Robert, 1996; Robert and Gravez, 1998).

Since the 1970s, the notion of protected areas moved on to a more general concept of nature conservation, then to a more dynamic one of nature management. Protected areas therefore need to be part of a broader regional approach to land (and sea) management (McNeely, 1994a; Agardy, 2001; Raffin, 2001; Boudouresque, 2002a). Furthermore, it is recognized that conserving nature requires a flexible approach in which local people should not to be excluded *a priori* (Boudouresque *et al.,* 2004). This new perspective was first given full legitimacy in the World Conservation Strategy (IUCN, 1980) and was converted into practical advice at the 3rd World National Parks Congress, held in Bali, Indonesia, in October 1982. The title of the congress proceedings ("*National parks, conservation and development: the role of protected areas in sustaining society*") gives a clear indication of the new direction being advocated (McNeely, 1994a). This approach (sustainable development) was then popularized and formalized at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992: "*That range of activities and development which enables the needs of the present generation of humans and all other species to be met without jeopardizing the ability of the biosphere to support and supply the reasonably foreseeable future needs of humans and all other species*".

Nowadays, the targets of the Marine Protected Areas (MPAs) are sixfold. **(i)** To set up conservatories for threatened species and habitats. **(ii)** To provide sites for public education on the environment (e.g. underwater nature trails, public awareness leaflets). **(iii)** To provide reference areas for scientific research. **(iv)** To provide spectacular landscapes for tourism (bathing, pleasure craft, snorkeling, diving). **(v)** To establish no-

take areas where fish density and sex-ratio make spawning possible, and which subsequently export eggs, larvae and adults to surrounding unprotected areas and therefore enhance catches by fishermen. **(vi)** To manage the different uses of the sea (e.g. commercial fishing, amateur fishing, pleasure boating and tourism) in a rational way, so that they do not conflict with each other or with conservation aims (Agardy, 1997; Dayton *et al*., 2000; Sumaila *et al*., 2000; Francour *et al*., 2001; Malakoff, 2001; Roberts *et al*., 2001; Boudouresque, 2002a; Boudouresque *et al.,* 2004). Obviously, MPAs, together with regional integrated management of user conflicts, result in economic benefits, both for fishermen and the tourism industry, in such a way that there should no longer be a need to try to set off environmental values against economic values (Ramos, 1992; Ribera-Siguan, 1992; Boudouresque, 1996). For example, it has been estimated that the tiny (20 km^2 of land and sea) Port-Cros National Park, French Riviera, produces, directly and indirectly, a mean annual turnover of 300 million € per year (IRAP, 1999; Boudouresque, 2002a).

Sustainable development and the flow of introduced species

Some introduced species are now of economic importance in the Mediterranean, being exploited by local fisheries (Oren, 1957; Galil, 1986; Spanier and Galil 1991; Zibrowius, 1991). The crab *Portunus pelagicus* has become the dominant crab in commercial catches all around the eastern Mediterranean, especially in Egypt. The prawns *Penaeus japonicus* and *P. monoceros* are also commercially exploited. In Israel and Egypt, they make up most of the shrimp catches. Off the Israeli coast, Lessepsian fishes constitute a third of the trawl catches. It is unclear, however, whether total stocks or even annual catches have actually increased in these regions, or if introduced species simply replaced native ones of equal economic value (Boudouresque, 1996, 1999b, 2002b). At any rate, the (possible) economic benefits of a species introduction should not be assessed simply on the basis of strict sale price, but on the basis of a wider view, taking into account the losses to other business activities and the cost of any damage that may result: these losses are usually “externalized”. This means that some people recoup the benefits, while the “externalized” costs are paid by others (e.g. McNeely, 1992, 1994b, 1996a, 1998; Bayon *et al*., 1998).

The harmful consequences of species introduction may affect various sectors of human activity (Fig. 2) (e.g. Kiernan, 1993; Boudouresque, 1999a, 2002b; IUCN, 2000): **(i)** Fisheries. In the Black Sea, the dramatic drop in fish catches is considered to be a consequence, at least in part, of the introduction of the comb jelly *Mnemiopsis leidyi* (GESAMP, 1997). **(ii)** Aquaculture. Most of the new diseases of bacterial or parasitic origin that strike marine cultures in many parts of the world (for example oyster culture) probably result from species introduction (Mazzola, 1992; Barber, 1997). In the same way, the worldwide

increase in blooms of unicellular planktonic organisms producing paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP) toxins may be due to the transportation of millions of cubic metres of seawater by ships (ballast water) from one ocean to another (Carlton and Geller, 1993; Hallegraeff, 1993; Belin and Martin-Jezequel, 1997; Carlton, 1998; Hamer *et al*., 2001). Such blooms often result in the temporary prohibition of the shellfish trade, with dire economic consequences for sea farmers. Finally, introduced species may prove to be successful competitors of oysters, as in the case of the mollusc *Crepidula fornicata* in Europe (Blanchard, 1995). **(iii)** Public health and tourism. Along the Israeli coast, painful stings are inflicted by the introduced jellyfish *Rhopilema nomadica*, and nets strung along the bathing beaches have proved to be ineffective (Galil *et al*., 1990; Spanier and Galil, 1991).

In the USA, alien plants and animals caused damage costing at least US$ 97 billion from 1905 to 1991. This is a very conservative estimate since data were available for only 79 species out of the 4 500 introduced to the USA (Kiernan, 1993; OTA, 1993; McNeely, 1996b). Nowadays, the economic costs of invasive species exceed US$ 100 billion annually (Magee *et al*., 2001). At worldwide scale, the direct economic costs of alien invasive species run into hundreds of US$ billion annually (IUCN, 2000; Magee *et al*., 2001).

In most of the areas colonized by *Caulerpa taxifolia* (hard bottoms and meadows of *Posidonia oceanica*), fish biomass has declined significantly, especially that of target fishes, and there is a decrease in their mean size (Harmelin-Vivien *et al*., 1999; Table II). In addition, fishing nets become clogged up with *C. taxifolia*, and can be spotted by fishes, which thus escape (Cottalorda *et al*., 2000; Boudouresque, 2002b). As a result there is a conspicuous decrease in catches, say the fishermen. They therefore move to more distant sites, which involves extra costs: more diesel fuel, more time and more powerful fishing boats (Durin, 2000; Boudouresque, 2002b). If the decline of the *Posidonia oceanica* meadows were to be confirmed in the long term, and considering the major role they play as spawning sites and nurseries for fishes, the negative impact of *C. taxifolia* on fish catch might further increase.

Table II. Decrease in mean species richness (number of species per transect), mean density (number of fish individuals per 10 m^2) and mean biomass (g wet weight per 10 m^2) of fish assemblages in sites colonized by *Caulerpa taxifolia* compared to reference sites at Cap Martin (French Riviera), expressed as percentage of reduction. From Harmelin-Vivien *et al.* (1999).

	Shallow sites	Deep sites
Mean species richness (number of species/transect)	- 23 %	- 31 %
Mean density (number of fishes/10 m^2)	- 36 %	- 31 %
Mean biomass (g/10 m^2)	- 57 %	- 42 %

A large proportion of Mediterranean economic activity is based on tourism. For example, the Provence and French Riviera region (Provence-Alpes-Côte d'Azur) is host each year to over 24 million tourists, who are mainly attracted by the sea: swimming, pleasure boating, scuba diving and snorkeling. Scuba diving is currently one of the driving forces that are contributing to the development of tourism. In the Mediterranean, increase rates of more than 10% per year are not uncommon. The homogenisation of the underwater landscape due to the spread of *Caulerpa taxifolia* is a negative factor rather than an attraction for divers: they hope to find gorgonians and fishes, a richly coloured fauna and flora, a variety of species and not a seafloor carpeted with *C. taxifolia*. As a result, this species has a negative impact on the development of scuba diving. Indeed, directors of the diving clubs of the French Riviera say that only beginners are still willing to dive on bottoms carpeted with *C. taxifolia*. To keep the custom of other divers, both local divers and tourists, they have to move to more distant sites still free of this seaweed, at extra cost (Durin, 2000; Boudouresque, 2002b). At the moment, only two diving clubs, located on the most densely colonized stretches of coast, are concerned (Durin, 2000). However, this reaction could be the harbinger of more widespread problems (Fig. 2) (Boudouresque, 2002b). Unfortunately, only preliminary data are available on the impact of *C. taxifolia* on non-commercial values, e.g. existence values (Bec, 2000; Boudouresque, 2002b).

All in all, the invasive species have a negative impact on specific diversity and on ecodiversity (Fig. 2). This is one of the most worrying forms of human impact, because it is irreversible at human scale (Table III): we know that in fact the eradication of an introduced species is generally impossible, especially if this has not been attempted at a very early stage. From this point of view, introduced species undermine in an irreversible way everything that has been done to protect biodiversity, whether through the protection of species or the protection of habitats. There would no longer be any point in setting up Marine Protected Areas if it were merely to protect uniform meadows of *Caulerpa taxifolia*, *C. racemosa* var. *cylindracea*, *Acrothamnion preissii* and/or *Womersleyella setacea*.

Table III. Ranking of the relative importance of human impacts, according to the time necessary for the impact to become reversible. From Alexandre Meinesz (pers. comm.), modified.

Rank	Time necessary for reversibility	Examples
1	One day through one month	Some local pollution events
2	One month through one year	Some local pollution events
3	One year through ten years	Overfishing (abundance of individuals), pollution, oil spills
4	Ten years through one century	Long-lived species destruction (macrophytes, vertebrates)
5	One century through one millennium	Overfishing (genetic shift)?
6	More than one millennium	Coastal development, species introduction, species extinction, climate change

But introduced species also have an economic impact. This has been entirely ignored in the Mediterranean countries, which is surprising since it is the Mediterranean that is the sea that is the most concerned worldwide from this point of view. The economic impact is undoubtedly, in most cases, greater than the ecological impact, but the cost is externalized, in such a way that those who pay are generally unaware of doing so. The economic impact of introduced species concerns industry, public health, aquaculture, fisheries and tourism. The importance of tourism in the Mediterranean (1/3 of tourism worldwide) is such that the impact on tourism is perhaps the most worrying aspect in the long term.

By undermining the policies for the conservation of species and habitats on the one hand and economic activities on the other, invasive species change the rules of the game and turn upside down the complex equilibrium that is the cornerstone of strategies of sustainable development (Fig. 2). In contrast to pollution, the impact of which diminishes with time and with distance, the impact of an invasive species has no limit in space (other than geographical) and may increase with time. Frontiers, whether administrative (Marine Protected Areas) or political (countries), do not exist for invasive species. The problem can thus only be dealt with at international level. It can only be understood if the full range of aims and resource uses is taken into account: it is thus *par excellence* a problem of sustainable development.

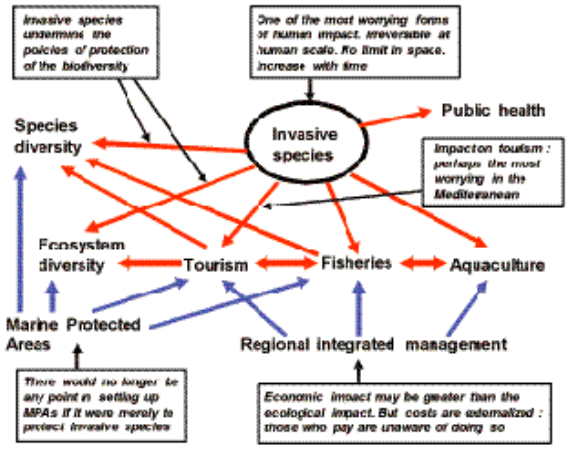

Fig. 2. Interactions between policies for the conservation of species and habitats, economic activities and invasive species. Blue arrows: positive impacts. Red arrows: negative impacts. Boxes and black arrows : comments.

International conventions and national legislation

Many international conventions (e.g. the Bonn Convention, Bern Convention, Barcelona Convention, Convention on Biological Diversity, Montego Bay Convention) recommend that countries that have ratified

them should take measures to avoid the introduction of species and, if introductions should occur, to attempt to limit their spread and their impact.

The Bonn Convention of 1979 (Convention on the conservation of migratory species of wild animals) states that Agreements concluded under the Convention for the conservation of individual species or of groups of species should provide for "*the protection of (the) habitats (of migratory species) from disturbances, including strict control of the introduction of, or control of already introduced, exotic species detrimental to the migratory species*". The Bern Convention of 1979 (Convention on the conservation of European wildlife and natural habitats) provides that "*each Contracting Party undertakes (…) to strictly control the introduction of non-native species*". The Protocol to the Barcelona Convention concerning Mediterranean Specially Protected Areas (Geneva Protocol of 1982) obliges Parties to take measures progressively to protect these areas. These may include the prohibition of the introduction of exotic species, as well as *"the regulation of the introduction of indigenous zoological or botanical species*" in protected areas. The EU Habitats Directive of 1992 requires member States to "*ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction*". The Convention on Biological Diversity of 1992 requires its Contracting Parties, as far as possible and appropriate (article 8h), "*to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species*" and "*to strictly control the introduction of non-native species*" (De Klemm, 1994, 1995; Glowka and De Klemm, 1996; Mooney, 1996; Magee *et al*., 2001).

The United Nations Convention on the Law of the Sea (Montego Bay Convention), in force since 1994, states that (article 196.1) "*States shall take all measures necessary to prevent, reduce and control (...) the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto*" (De Klemm, 1994, 1995). It should be stressed that the Montego Bay Convention, unlike preceding conventions, is legally binding.

With regard to national legislation aimed at preventing and combating the introduction of species in the marine environment, 5 levels may be considered (Boudouresque, 2002c). **(i)** Level 0 corresponds to the absence of legal texts, whether specific or not. This is the case, in the Mediterranean, in Algeria, Cyprus, Greece, Monaco, Tunisia and Turkey (De Klemm, 1995). **(ii)** Level 1 corresponds to the existence of texts designed for purposes other than the prevention of the introduction of

species, but which might be sidetracked from their initial aim. Italy, France, and some other Mediterranean countries belong to this category. In France, the Act of 2 February 1995, Article L-211-3, provides that "*in order not to damage the natural environment of wild fauna and flora, the introduction into the natural environment deliberately, negligently or imprudently of any specimen of undomesticated or non-cultivated animal or plant species which are not native to the territory of introduction*" (translated from French) is prohibited. The administration may destroy, or arrange for the destruction of specimens introduced illegally. Any costs incurred may be charged to the person guilty of the offence (De Klemm, 1995). Unfortunately, the decree specifying the conditions for implementation of Article L.211-3 was never issued, and in 10 years, no explanation has ever been offered in response to the numerous requests addressed to the French ministry of the environment. The Article of the Act of 5 February 1995 dealing with the introduction of species is still not in force in France. **(iii)** Level 2 corresponds to the existence of specific texts on species introduction. However, these texts are naive in that they deal primarily with deliberate introduction in the natural environment and not with the importation and possession of exotic species (which may escape: "fugitives"), nor with measures for decontamination and quarantining to prevent the introduction of species that are not deliberately imported ("stowaways" and "hitch-hikers"). Yet, and this is the case in the marine environment, deliberate introduction is rare. The vast majority of introductions are accidental: species transported with ballast water, species accompanying aquaculture species, species attached to the hulls of ships (fouling), species accompanying international trade (for instance, carried in containers), species escaping from aquariums, etc. In addition, if the public can own exotic species, it would be very naive to imagine that it would be possible to identify the author of an accidental introduction: one cannot place a policeman in front of every door (and besides, no one would wish to!) (Boudouresque, 2002b, 2002c). The Spanish legislation, that is no doubt the most advanced in the Mediterranean, comes within this Level 2: the Act of 27 March 1989 and the decree of 8 September 1989 (De Klemm, 1995). France would be placed at a similar level if decree of application of the Act of 5 February 1995 had been issued. **(iv)** Level 3 corresponds to the drawing up of a black list (= "dirty list") of exotic species known, elsewhere in the world, as having been introduced or as exhibiting invasive behaviour: a threat to native species and ecosystems and/or negative economic impact. The importation and possession, even on a private basis, of a species on the black list is prohibited. No Mediterranean country has legislation at this level, in contrast to Great Britain, for example. **(v)** Level 4 corresponds to the drawing up of a white list (= "clean list"). Any importation of exotic plants or animals is prohibited in New Zealand, unless it figures on a list of authorised species, for which the risk of introduction is slight and where, should it occur, the damage to native species and

natural habitats would probably be negligible (Animals Act of 1967, amended in 1990; Biosecurity Act of 1993). The same is true in Australia, where the Australian National Parks and Wildlife Service monitors the importation of all living organisms thanks to the Wildlife Protection (Regulation of Exports and Imports) Act of 1982 (Pollard and Hutchings, 1990; De Klemm, 1995).

All Mediterranean countries have ratified at least one of the international conventions cited above, in some cases more than 20 years ago. Nevertheless, most of them have not yet drafted a single text of law to apply the recommendations that they make. With regard to the introduction of species, most of the Mediterranean countries would thus appear to be in a total juridical vacuum, in contrast to the countries of Northern Europe and above all the United States, Canada, New Zealand and Australia.

It is worth wondering about the considerable gap that would appear to have arisen between the international conventions dealing with the environment, in particular the protection of threatened species, and the prevention of introductions of species, and their actual implementation at national level. Similarly, it is difficult to understand why the civil servants from ministries responsible for the environment who have taken part in international meetings and in the drafting of recommendations, and have subsequently approved them, forget all about them a few days later as soon as they get home. The signing of these conventions, and sometimes the annual working meetings they give rise to, are given intensive media coverage. Why then is their implementation so slight as to be sometimes non-existent?

There are several possible explanations for this inefficiency on the part of the technocratic administrative structures (i.e. the civil servants at the ministries of the environment). **(i)** The lack of time of the civil servants, who have to rush from one international convention meeting to another, and do not have the time to implement them. **(ii)** The at least partial redundancy between certain of these conventions, which can be confusing. **(iii)** The civil servants' poor knowledge of law. **(iv)** The poor level of scientific culture among certain civil servants, who may themselves be incapable of appreciating the value of certain articles of the international conventions, in particular those dealing with the protection of species and the introduction of species, and who are thus not highly motivated to implement them. **(v)** Pressure from lobbies on the national agencies responsible for the environment. These lobbies (e.g. aquariologists, importers of exotic animals) may be the underlying reason for the reluctance of the national agencies to put into practice the prevention of species introduction, or, in the case of France, to issue the decree of application of Article L.211-3 of the Act of 2 February 1995. **(vi)** Finally, the lack of professionalism, or naivety, of elected officials, who do not follow closely the work of the agencies (or ministries) for which they are responsible.

Whatever the case may be, these attitudes, whether they are deliberate or stem from a certain amateurishness, incompetence or irresponsibility (corruption may probably be ruled out), raise a real problem in terms of democratic procedures. In states subject to the rule of law, can it be considered normal that international conventions, signed and ratified by elected officials, that a law voted quasi-unanimously by elected members of parliament (for instance, in France the Act of 2 February 1995), be flouted by non-elected civil servants whose role is precisely to implement the decisions taken by the elected officials?

CONCLUSION

Introduced species are one of the major environmental problems of the 21st century, at planetary scale. Through their impact on species and habitats and on resource uses and the economy, they seriously undermine the notion of sustainable development. Clout (1998) suggested that, as a result of the widespread homogenisation of flora and fauna, the Earth might now be entering a new Era, the "Homogocene". All the international conventions, signed by all the Mediterranean countries, emphasize the importance and the urgent necessity of taking steps to limit introductions of species and their impact. While it is reassuring to know that they exist, these international conventions are nonetheless somewhat inadequate, often unrealistic and more or less ineffective: all they do is recommend the introduction of Level 2 legislation. In addition, with the exception of the Montego Bay convention, they are not legally binding.

The fact remains that although species introduction is a much more serious problem in the long term than pollution, because it is irreversible, no Mediterranean country has really taken stock of the situation or introduced legislation in accordance with the (albeit not very ambitious) international conventions to which it is a signatory. The blame lies primarily with the civil servants in government agencies: their lack of time, naivety, amateurishness, lack of scientific expertise (probably not corruption). But responsibility also lies with many scientists, who feel flattered at being consulted and believe that being a good taxonomist or an expert on the digestive enzymes of fishes (for example) also makes them competent in matters of conservation biology, and who thus serve as an alibi for the men from the ministries. Finally, the lobby of the chemists, who have devices for measuring levels of this or that pollutant, and who thus have a vested interest in convincing the ministries that pollution is the major environmental problem in the Mediterranean, must also take their share of the blame.

The fact that, in addition to the harmful ecological impact, the introduction of alien species could result in economic damage and the failure of sustainable development strategies, should lead decision makers

and politicians to feel more concerned by this problem and prompt them to bring the civil servants of their Ministries to heel, to implement existing regulations, and above all to improve legislation.

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